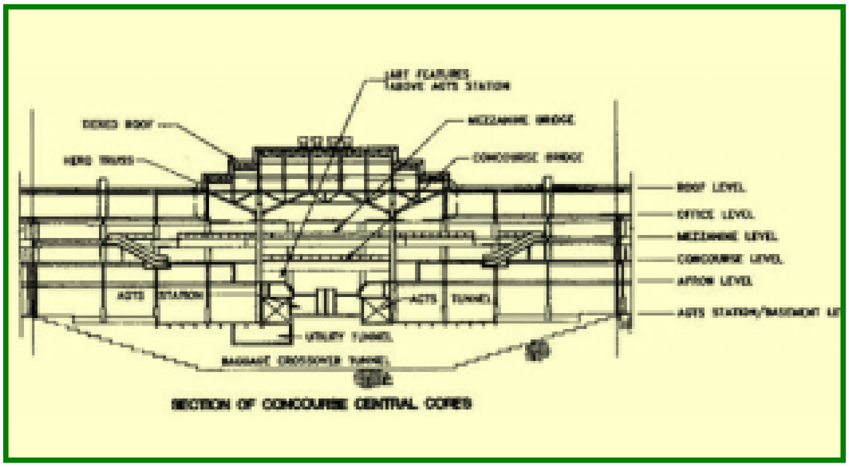


NEW FLIGHT PLAN

Steel provided not just design flexibility, but also created a unifying aesthetic for Denver's new airport

By Richard Weingradt, P.E. and John Davis, P.E.

High on the plains overlooking the skyline of Denver, the Platte River valley, and the rugged peaks of the Rocky Mountains, stands the world's second largest airport (by land area). As this country's last major new airport of the 20th century, Denver International Airport (DIA) is currently getting rave reviews.

Especially encouraging to the City of Denver is the airport's praise from its travelers; it comes after mixed public opinion as to the true need for a new airport, and a rocky start that included constant lambasting by the media and skeptics who decried both its conception and construction.

According to Norm Witteveen, Deputy Manager of Aviation, Planning and Development, "users are very positive about DIA, especially frequent fliers, both those flying in and out as well as those just transferring through." DIA is proving to be one of the best investments the people of Colorado and the U.S. have made. "It is operationally and financially a big success. All those with a stake in its operation consider it a huge success."

The American Society of Civil Engineers (ASCE) honored DIA with its coveted Outstanding Civil Engineering Achievement Award in 1997. The prestigious award recognizes remarkable construction projects that "demonstrate contributions to the well-being of people and communities, resourcefulness in planning and solving engineering challenges, pioneering in the new uses of methods and materials, and innovation in design and construction."

Some of the funding for DIA was used to purchase impressive public art, such as the scuplture pictured at right. In addition, the exposed steelwork also has a sculptural quality.

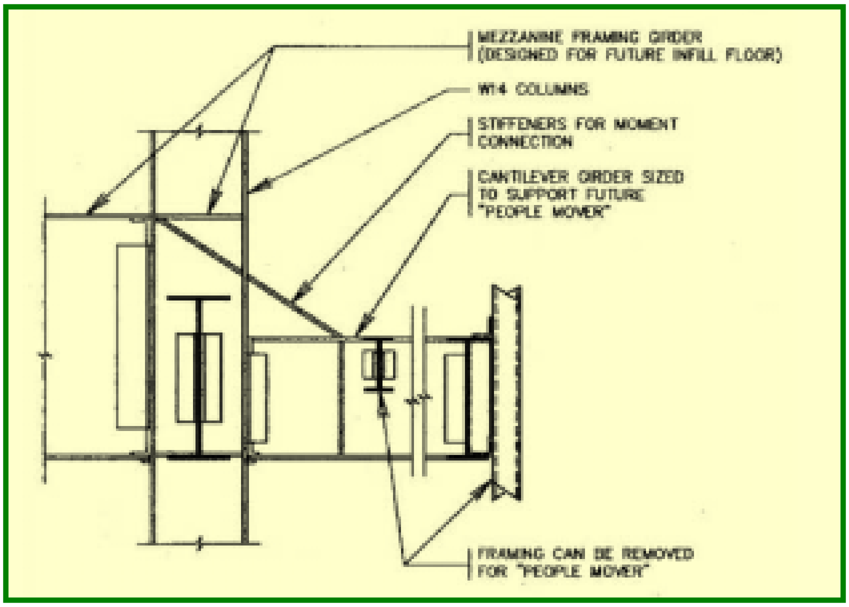
Structural Steel Is Key

Most photographs of the new airport concentrate on the exterior. However, users are perhaps even more impressed with the interior elements, especially the airside concourses and landside terminal. Both structures rely heavily on the innovative use of structural steel for strength. Don Strauch of Wong Strauch Architects, the designers for the United Airlines enlargement of Concourse B, notes that the use of structural steel allowed major tenant modifications to be amassed during construction. “Incorporating the various United Airline changes such as widening the concourse, adding gates and sub-cores, increasing the height of the central core, and adding the UAL-parts facility building would have been much more difficult had structural steel not been used.”

Much has been reported about the terminal fabric roof whose shape mimics the peaks of the nearby Rocky Mountains. It is one of the largest tensile membrane structures in the world — 376,332 square feet, 400 tons; it is held up by structural steel members. Key supports include 34 steel masts and 25 miles of steel cables.

The truly classical use of structural steel as the main building system, however, is exemplified in the airport’s concourses — the first and last spaces the traveler sees as he or she boards or disembarks. Travelers have been highly impressed by the grandiose spaces of the concourses’ central cores, which rise 10-stories high from the train platforms to skylights at the roof.

“Because the structural system is left exposed in the cores, we wanted it to have a light and airy feeling,” states the principal project architect, Jim Allred of then Seracuse Lawler Allred Fisher/TRA. “The structural engineers at Richard Weingardt Consultants came up with some



The mezzanine was designed to accomodate a future automated people mover system.

very inventive steel designs that did just that: exposed structural steel structures that look like art sculptures."

Design Considerations

Of the many design parameters and requirements demanded, assuring continued flexibility, serviceability and expandability far into the future was one of the most critical. For this reason, the primary superstructure was designed as structural steel; framing systems took many forms and addressed a myriad of structural requirements throughout this complex facility. Not only can each concourse be easily expanded in length, but two additional concourse buildings can be added in the future. Jeff Reddy of Reddy & Reddy Architects, the architects responsible for the Concourse A international expansion and interior design, states, "The steel structural frame for the DIA concourses has proven to be economical and flexible as well as an aesthetic design solution. Additions and/or modifications to the concourses can be easily achieved with the steel frame design. Structural depths and spans are flexible, which is important in areas where vertical clearance is critical but limited, due to the building's relationship to the loading aircraft. The exposed structural frame over the main public areas is an economical solution that is visually impressive over the large, open floor plan."

Structural engineering for DIA's Concourses A, B and C, was completed by Richard Weingardt Consultants, Inc. The three concourses represent 4.3-million-sq.-ft. of structure which cost $124.5 million. The concourses used approximately 30,000 tons of steel with an average cost of approximately $14.00 per square foot.

Constructed over a deep foundation basement, the apron-level framing utilized a composite steel system. This framing had to be designed to accommodate a variety of loading conditions, including 155,000-lb. aircraft push-back tugs which can traverse across the building at several locations. There was also the need to provide tenant-developed openings through the apron-level framing for the various baggage system components. The use of structural steel provided the flexibility necessary to not only accommodate high vehicular loads, but also to achieve maximum flexibility, both at the time of design and when future modifications are required.The concourse level of these buildings, the primary public level which houses the aircraft loading gates, required even greater design and future flexibility. The composite structural steel framing system utilized was specifically designed to allow the easy installation of multiple moving walkways to assist passengers traveling from gate to gate and to the central cores.

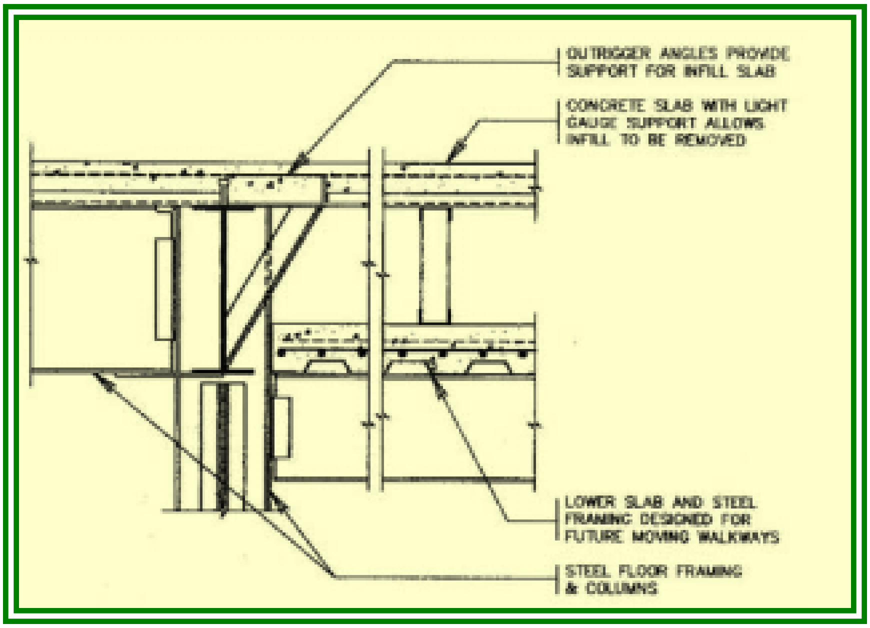
These depressed pits, which extend virtually the entire length of all the holdrooms, are designed to accommodate single or multiple pathways of varying lengths, depending on the need of the airline tenants and concourse operations. With the ability to extend each of the concourses by any combination of gate modules, this built-in moving walkway capacity allows them to be deleted where walk distances are short, and added later when expansion results in longer holdroom lengths.

Structural Systems

The design of the concourses through the central cores, along the full length of the holdrooms, and through the service subcores, results in a very wide passenger corridor without column obstructions. This allows travelers to move freely without congestion and enhances the overall user-friendly atmosphere of the airport. The aircraft boarding gates are located on either side of the concourses, well away from the traffic corridors with adequate room to accommodate the passenger loads from any size aircraft.

The central core module of the concourses provides an extremely high level of efficiency. Upon exiting the AGTS (Automated Ground Transportation System) trains at the station in the basement level of the central cores, travelers can immediately look upward for the full 104-ft. height of the concourse. Passengers are guided up escalators or elevators past the apron level and directly to the concourse level. This level incorporates the train station below, with walkway bridges bisecting this open area.

At the concourse level, passengers locate directions to the appropriate boarding gates and a variety of retail outlets and restaurants. The pedestrian bridge, which crosses above the AGTS station, spans 83 feet using composite structural steel and incorporates provisions for moving walkways. The design incorporated not only high loading conditions, but also consideration of vibration resistance across this length. Framing member sizes vary from W18 to W36 shapes with a 6-1/2" composite concrete slab. Typical bay spacing at the concourse level is 32-ft. x 32-ft.



The floor framing design allows for maximum flexability.

Mezzanines

Above the concourse level is the mezzanine. At the central cores, the mezzanine encircles the opening to the AGTS station, which is crossed by two separate pedestrian bridges. This composite structural steel framing allowed a variety of modifications necessary to accommodate individual airline tenants in offices around the perimeter of the central cores.

Along the full length of the holdrooms, service sub-cores, and across the central core pedestrian bridges, an innovative framing system was developed at the mezzanine level which allows the easy addition of a future automated people-mover system. At both the sub-cores and central cores, guideway trench framing is already in place and has only been temporarily framed over to provide a flat floor surface until such time as a people mover is installed. In the central cores, these trenches extend along the current pedestrian bridges over the concourse and AGTS stations below.

At the holdrooms, the structural steel columns and beam framing have been designed to include cantilevered support beams for the future guideway. In addition, the open framing lines of the mezzanine level above the passenger gates can be in-filled in the future with steel framing to provide additional floor space at any or all bays along the holdroom lengths.

Above the mezzanine level is a variety of framing and loading conditions which vary between the three concourses. At Concourse B, for example, an additional level was added to accommodate tenant offices which raised the tiered roof construction one full floor higher. Along the holdrooms and sub-cores of Concourse A, provisions were designed for corridors for international passengers in lieu of roof framing. Again, the use of structural steel provided the maximum designed flexibility, current serviceability, and future modifications. Pre-engineered steel bar joists and metal deck was used for roof framing at areas where future modifications are not anticipated; 20"- deep joists at 4' centers were typically used and the design accommodates up to 102 psf snow drifting. Structural steel framing was used extensively for future requirements at other locations.

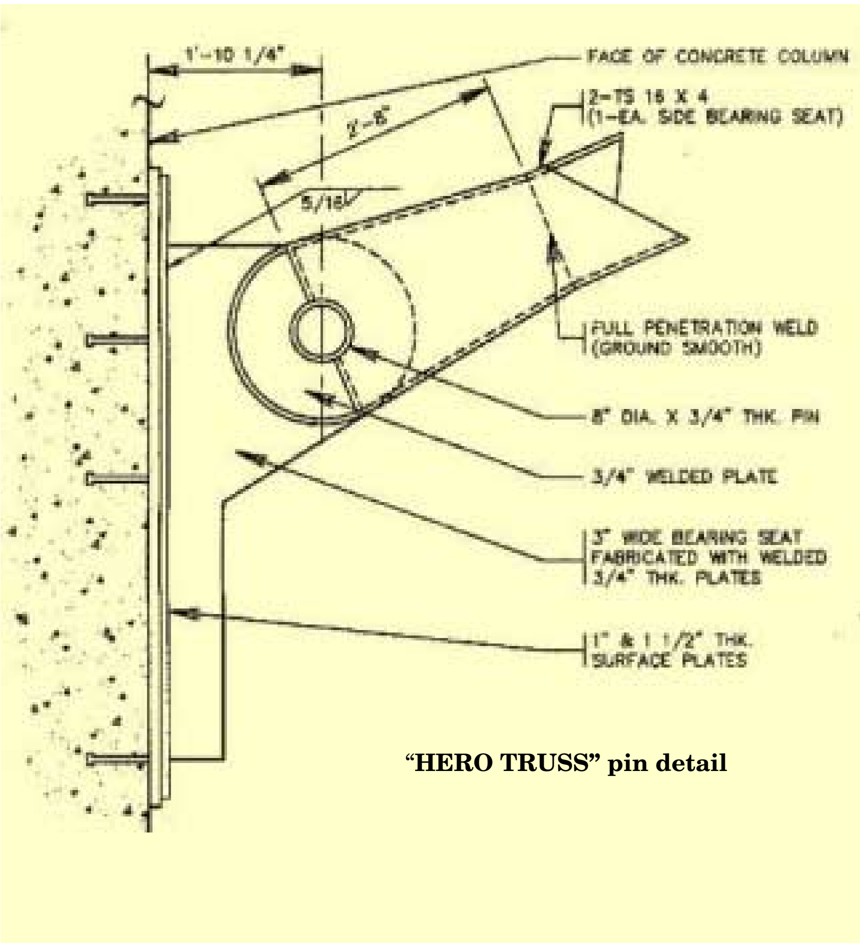
The roof framing of the central cores is completely exposed and is tiered up to a full height of nearly 10 stories above the AGTS station below. Each tier is encircled with glass, providing natural light throughout the levels below. The roofs of the holdroom modules include a continuous clerestory design with glazing along both sides. Combining composite structural steel and bar joists at the sub-cores allowed the design of framing and diaphragms necessary for the possible addition of ramp-control towers at these locations in the future.

Hero Trusses

One of the most prominent and visibly striking structural elements at the airport are the "hero trusses" spanning across each concourse's central cores. These huge steel trusses earned their name because they are visually impressive and do so much structurally. Two sets of these trusses span nearly the full width of the central cores and support the tiered roof systems across a 150' length, which is open through the full height of the cores.

The hero trusses are designed using structural steel tube sections for both their visual symmetry and structural properties. The top and bottom chords are constructed of 8" x 6" hollow structural sections with the webs at 6" x 4". Architectural-quality welded joints were used throughout the truss fabrication, which was done in full-span section lengths.

** The hero trusses use long, diagonal compression struts as part of their support and web design. These struts, which use 16" x 4" steel HSS members, end with large, architecturally-detailed pin joints at the supporting columns. This connection uses carefully designed and detailed plates and stiffening elements to transfer



"HERO TRUSS" pin detail

loads across the pin in a manner that replicates highway and railroad bridge construction of the past. The 8"-diameter pipe pin passes through two¾" bearing plates to transfer the axial loads.

Fabrication of the hero truss sections and construction tolerance of the supporting reinforced concrete columns had to be nearly perfect. In order to assure the best possible member alignments when making the final connections, the contractor had to select the best time of day to allow for thermal effects in the members. All sets of the hero trusses in the three concourses were erected without significant problem.

High Wind Forces

The concourses' multiple lateral systems were designed to resist very high wind loading corresponding to Uniform Building Code 85 mph exposure C conditions, and Zone 1 seismic. To achieve this resistance, a variety of lateral methods were employed. At the central core and sub-cores of each concourse, reinforced concrete shear walls were used in combination with the reinforced concrete slab utilized by the composite steel floor framing.

At the holdroom modules, however, a complex welded moment-resisting structural steel frame was used.

Frames were designed at each of the column lines across the lateral dimension of the holdrooms and included all roof, floor, moving walkway recesses and columns to provide a high level of building sway control. Frame floor members are typical W24 x 76 with W14 x 120 columns. Frames are located on a 32' bay spacing.Project Team

In the longitudinal direction, the exterior column lines used braced moment welded connections to support the holdrooms without assistance from the adjoining sub-cores or central cores. The building structural isolation joints between the concourse modules were sized primarily for thermal control; the sway control designed into the moment frames did not result in wider joints being necessary.

Future Considerations

Because of the flexibility and strength of structural steel, systems that could be designed using this method played a crucial role in building one of the finest international airports in the world. It will continue to be a significant element in the future as DIA expands and changes to handle the needs of America's future air traffic. The existing steel structures have the unique capacity and versatility to be easily modified and added on to. DIA will long stand as a stellar example of one of the many outstanding engineering marvels U.S. engineers and builders have helped create using the latest designs and best construction materials available.

Richard Weingardt is CEO and John Davis is President of Richard Weingardt Consultants, Inc. of Denver, Colorado. Weingardt was the 1995-96 National President of the American Consulting Engineers Council. RWC, Inc. has completed 3,500 major structural projects worldwide since its inception in 1966.

Project Team

Structural Engineers:
- Richard Weingardt Consultants, Inc

Architects:
- Base Building Architects
- Allred Fischer Seracuse Lawler & Partners and TRA, Joint Venture

General Contractors:
- PCL Construction Services
- Hensel Phelps Construction Company
- M.A. Mortenson

AISC Member Steel Fabricators:
- PKM Steel Services, Inc.
- Hammert's Iron Works,